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Confounding variables in the discriminated Irt procedure.

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CONFOUNDING VARIABLES IN THE DISCRIMINATED IRT PROCEDURE

A Thesis Presented

By

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ABSTRACT

Confounding Variables in the Discriminated IRT Procedure

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When discriminated IRT procedures have been used to determine preference relations among temporally extended operants, deviations from predictions of the matching law have been found (Hawkes and Shimp, 1974). Using a yoked-control procedure, the present study shows that keypecking in the discriminated IRT procedure has two sources of strength, that arising from the stimulus-reinforcer contingency and that arising from the response-reinforcer contingency. Three out of four yoked birds autoshaped to the keylight, and all lead birds showed evidence of control by the keylight under some conditions. As any control of keypecking by the keylight, either discriminated or autoshaped, contributes to deviations from matching, the discriminated IRT procedure does not permit one to draw strong conclusions about preference relations among IRTs.

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INTRODUCTION

When a pigeon pecks a key on a VI reinforcement schedule the effect of the reinforcer may be to strengthen not just the keypeck itself but any behavioral sequence of which the keypeck is the terminal link. Thus the pigeon may be seen as engaging in a number of responses or response chains of various durations, each of which is terminated by a keypeck. The time that elapses between successive keypecks (the interresponse time or IRT) is an index, though by no means an infallible one, of these other responses, and a frequency distribution of IRTs gives us some notion of the pigeon's relative preference for the various responses. To the extent that IRTs provide a valid measure of these responses we should expect them to show the same dynamic properties as directly observable response classes, e.g. sensitivity to reinforcement magnitude and frequency, generalization, matching, etc. (cf. Morse, 1966). In turn, we should be able to study these phenomena using IRTs as a dependent variable.

Skinner (1938) noted that under FI schedules any variability in response rate would result in the differential reinforcement of relatively long IRTs while under FR schedules variability in response rate would result in the differential

reinforcement of relatively short IRTs. The fact that FR schedules typically control a higher rate of responding than FI schedules suggests that IRTs are in fact sensitive to reinforcement contingencies. Anger (1956, 1973) differentially reinforced specific classes of IRT and found that overall response probability could be altered, thus supporting the position that IRTs may be used to define response classes. The organism is necessarily engaging in some behavior between monitored responses, and it is presumably this behavior that is affected by the reinforcement contingency. Indeed, Wilson and Keller (1953) found that rats on a DRL (30) schedule engaged in stereotypic sequences of responding between barpresses, though Anger (1956) found that observable patterns of interim behavior were not necessary for interresponse times to come under the control of reinforcement contingencies.

Shimp (1968) showed that preference for various interresponse times, like preference in two-key choice experiments, could be manipulated through differential magnitude and frequency of reinforcement. Subsequently, he discovered that if the matching law is construed as applying to response durations rather than response frequency, it predicts preference relations among IRTs (Shimp, 1969). Specifically, he found that, given equal reinforcement rates for each of two IRT classes, the relative frequency of a particular IRT was equal to its relative length. Thus time spent engaging in each response class, given equal reinforcement, was approximately equal, provided that the absolute rate of reinforcement

exceeded a threshold of 20 or 30 reinforcements per hour (Shimp, 1970). These results were confirmed, whether responses were confined to a single key or were executed on separate keys (Moffitt and Shimp, 1971).

However, when Hawkes and Shimp (1974) attempted to extend these findings to a wider range of IRTs than had previously been used, they were unsuccessful. Within certain parameters their results were predicted by the matching law; given equal rates of reinforcement, responses terminating IRTs of $\underline{t}$ seconds occurred twice as frequently as responses terminating IRTs of $\underline{2t}$ seconds. Outside of these parameters, however, Hawkes and Shimp failed to confirm predictions of the matching law, and they concluded that the matching law may be a special case of some more general preference function.

The present experiment assesses the conclusions of Hawkes and Shimp by asking if the deviations from matching that they observed are the result, not of some characteristic of choice behavior in pigeons, but rather of confounding variables inherent in the discriminated IRT procedure, the procedure used by Hawkes and Shimp.

In each of the conditions of the Hawkes and Shimp study two classes of IRT were reinforced. The relative duration of the IRTs was held constant across conditions, but the absolute duration of the IRTs varied from IRT pairs whose midpoints were .42 seconds and .90 seconds to those whose midpoints were 8.75 seconds and 19.5 seconds. In every case the longer IRT of each pair was

slightly more than twice as long as the shorter IRT, so that the prediction of the matching law was held constant; specifically, the predicted relative preference for the shorter IRT was held constant at .70. Approximate matching was obtained for the range of IRT pairs whose shorter members were between 1.5 and 4.0 seconds. For IRT pairs whose shorter members exceeded 4.0 seconds, overmatching was found; that is, there was a greater preference for the shorter IRT than was predicted by the matching law. For IRT pairs whose shorter member was less than 1.5 seconds, undermatching occurred, that is, a lower-than-predicted preference for the shorter IRT.

In order to facilitate rapid acquisition of a pattern of responding in which keypecks were confined mainly to the criterion IRTs, Hawkes and Shimp used the keylight as a discriminative stimulus. The keylight would come on at the lower bound of each IRT and go off at the upper bound unless a keypeck occurred. Thus the keylight served as a signal that one or the other IRT had elapsed and that food was potentially available for keypecking. The houselight was on at all times except when the keylight was on or the food hopper was up. With the aid of these discriminative stimuli, pigeons quickly learned appropriate patterns of responding. Earlier research (Moffitt and Shimp, 1971) indicated that the discriminative stimulus sharpened the IRT distributions without affecting the preference between the IRT pairs.

The range of IRTs used by Moffitt and Shimp, however, did not include the values at which Hawkes and Shimp found deviations from matching. It is possible therefore that the use of discriminative stimuli contributed to the anomalous results. Specifically, since every presentation of food was preceded by the presentation of the keylight, it is possible that pigeons were autoshaping to the keylight. Parametric studies of autoshaping by Gibbon, Baldock, Locurto, Gold, and Terrace (1977), Terrace, Gibbon, Farrell, and Baldock (1975), and Perkins, Beavers, Hancock, Hemmendinger, Hemmendinger, and Ricci (1975) suggest that the longer IRT conditions used by Hawkes and Shimp would be more likely to foster autoshaping than the shorter ones. Acquisition of autoshaping was facilitated by a high ratio of intertrial interval to stimulus duration, and a high ratio of reinforcement to stimulus presentation. Hawkes and Shimp reported that the behavior of their pigeons was tightly controlled by the reinforcement contingencies: over 90% of all keypecks fell within or just outside the two reinforced classes of IRT. Therefore the interval between keylight presentations correlated well with the IRT condition; both the ratio of intertrial interval to stimulus duration and the proportion of reinforced stimulus presentations increased with the absolute duration of the reinforced IRTs.

Since the stimulus signalling the first IRT had to be passed by in order for the stimulus signalling the second IRT to occur, any autoshaping would have promoted overmatching; that is, to the

extent that pigeons pecked the light whenever it came on, overmatching would have occurred. Thus the overmatching which occurred in long IRT conditions may have been due to the fact that those are the conditions that foster autoshaping.

In addition to the possibility that it controlled autoshaped keypecks, the keylight may have contributed to the pattern of results by virtue of its role as a discriminative stimulus, since discriminative stimulus control is also typically enhanced by long interstimulus intervals (Taus and Hearst, 1970). To the extent that keypecking in the Hawkes and Shimp experiment was controlled by the keylight rather than temporal properties of responding, overmatching would have occurred. Thus discriminated IRT procedures may be inappropriate for answering questions about preference relations among IRTs.

The present study attempts to assess this possibility by determining the extent to which the discriminated IRT procedure fosters autoshaping and the extent to which keypecking is under the discriminative control of the keylight independent of temporal properties of responding. Certain pigeons, the lead pigeons, were exposed to the identical contingencies employed by Hawkes and Shimp. Other birds were yoked to these pigeons in such a way that they were exposed to the same stimulus-reinforcer contingencies as the lead brids, but there were no experimentally-imposed consequences for keypecking. Any keypecking in these birds was therefore autoshaped keypecking rather than operant keypecking.

The relationship between the pattern of responses in the lead birds and the onset of the keylight was monitored, and speed of transfer between experimental conditions was evaluated. If transfer between conditions were rapid, and if keypecking were largely confined to the keylight,we could conclude that keypecking was, to some extent, independent of temporal properties of responding, and we would be unable to draw strong conclusions about preference relations among IRTs.

C H A P T E R I I

METHOD

Subjects

Eight naive White Carneaux pigeons were maintained at approximately 80% of their free-feeding weight.

Apparatus

Four Lehigh Valley Electronics two-key experimental chambers were interfaced with a ModComp II computer. The computer arranged the presentation of stimuli, delivered reinforcers, and recorded data from one bird (the lead bird) in each condition. Standard relay equipment and counters were used to record the data from all other birds in each experimental condition. Exhaust fans provided ventilation, and 80 db. white noise helped mask extraneous noises.

Procedure

The eight birds were divided into two squads of four birds each, the A squad and the B squad. Squads were run in succession and in the same order (A birds first) seven days per week. There were three experimental conditions which were varied to control

for sequence effects. Both squads were run in all conditions. The parameters of the three conditions corresponded to three of the ten sets of parameters studied by Hawkes and Shimp. The parameters of the short IRT condition (the .4 sec condition) are those at which they typically found undermatching (a lower-than-predicted preference for the shorter IRT), those of the medium IRT condition (the 2 sec condition) are those at which they typically found matching, and those of the long IRT condition (the 8 sec condition) are those at which they typically found overmatching (a greater-than-predicted preference for the shorter IRT). Within the limits of the equipment, each experimental condition was identical to one of these three conditions used by Hawkes and Shimp.

In all experimental conditions the availability of reinforcement was determined by two concurrent VI (120) schedules corresponding to two response classes, that class of keypecks terminating a relatively short interresponse interval and that class terminating a relatively long interresponse interval. Thus in each condition only two classes of IRT were reinforced. When one VI schedule timed out the other schedule stopped timing until the reinforcer was collected by a response terminating the appropriate IRT. Thus the average rate of reinforcement given optimal performance was close to one per minute. The computer determined that the probability that a particular IRT would be the next one to be reinforced was always 0.50. There were no cues in the experimental chamber to indicate which IRT would be the next one

to be reinforced.

Reinforcement consisted of 3.0 sec access to Purina Pigeon Chow. This reinforcer duration was 50% longer than that used by Hawkes and Shimp in order to insure that the yoked birds received food, since, unlike the lead birds, they might not have been optimally oriented, i.e., facing the key or feeder, when reinforcement was delivered. Except for a light over the food hopper, the chamber was dark during reinforcement.

The upper and lower bounds of each IRT for the three experimental conditions are indicated in Table 1. Thus the independent variable was the absolute duration of the IRT pairs. Note that the relative duration of IRT pairs was approximately constant. We may show this by calculating the relative reciprocal of the shorter class of IRTs using the formula:[1]

$$\frac{\frac{1}{X_L} + \frac{1}{X_U}}{\frac{1}{X_L} + \frac{1}{X_U} + \frac{1}{Y_L} + \frac{1}{Y_U}}$$

where X = shorter IRT, Y = longer IRT, L = lower bound, and U = upper bound. The relative reciprocal of the shorter IRT is approximately 0.70 for all three experimental conditions (see Table 1).

TABLE 1

PARAMETERS OF REINFORCED IRT CLASSES

Experimental conditions	Shorter IRT class (seconds)	Longer IRT class (seconds)	Relative reciprocal of the shorter class
.4 sec condition	.40 - .70	1.10 - 1.60	.72
2 sec condition	2.00 - 3.00	5.20 - 6.20	.70
8 sec condition	8.00 - 9.50	19.00 - 20.50	.69

Discriminative stimuli. As in the Hawkes and Shimp study, the keylight was used to indicate when pecking conformed to either of the two IRT classes that were being reinforced in that particular condition. Pigeons were placed in dark chambers and the house light came on when the session was begun. After a keypeck the houselight remained on until the time corresponding to the lower bound of the shorter IRT elapsed. At that time the keylight came on and the houselight went off until the upper bound of the shorter IRT was reached. The keylight then went off and the houselight came on until the lower bound of the longer IRT was reached. Once again the keylight came on and the houselight went

off for the duration of the longer IRT, at the end of which the lights returned to their state prior to the initial keypeck. Every keypeck had the effect of resetting the timer and starting the sequence anew. Thus, a keypeck that occurred when the key was dark reset the timer but had no visual consequences. A keypeck to the lighted key had one of two effects. If the VI schedule had not yet timed out for that IRT, or if the next reinforcer were scheduled for the other IRT, a keypeck turned off the keylight, turned on the houselight, and reset the timer. If the schedule had arranged a reinforcer for that IRT, a keypeck turned off the keylight, turned on the hopper light, and raised the food hopper for three seconds. At the end of three seconds the hopper was withdrawn, the hopper light went off, and the houselight came on. At this point a response had to occur to begin the sequence again. The IRT of the first keypeck after reinforcement was not considered in the data analysis.

Yoking conditions. In each condition only one experimental chamber was interfaced with the computer, and therefore only one bird out of four (the lead bird) was exposed to the response-reinforcer contingencies outlined above. The remaining three chambers were yoked to the lead chamber so that the events in the lead chamber occurred simultaneously in all of the other chambers irrespective of the behavior of the pigeons in those chambers. Thus there were no contingencies on the behavior of the yoked birds.

Two birds out of each squad of four were yoked birds throughout the experiment. The other birds alternated between being lead and being yoked according to the schedule in Table 2. Thus in Condition 3 Bird A_2 was the lead bird for the A squad and Bird B_2 for the B squad; all other birds were yoked. A_2 was reinforced according to the parameters of the .4 sec IRT Condition and B_2 according to the parameters of the 8 sec IRT Condition.

TABLE 2

RUNNING CONDITIONS FOR EACH SQUAD

Condition number	Number of sessions	A Squad		B Squad	
		Lead Bird	IRT condition*	Lead Bird	IRT condition*
1	36	A_1	2 sec	B_1	2 sec
2	20	A_1	8 sec	B_1	.4 sec
3	29	A_2	.4 sec	B_2	8 sec
4	45	A_1	2 sec	B_1	2 sec
5	37	A_2	8 sec	B_2	.4 sec
6	30	A_1	.4 sec	B_1	8 sec

*IRT condition indexed by lower bound of shorter IRT.

Terminating the conditions. Each experimental session was terminated when 30 reinforcers had been earned. Each condition was run until the behavior of the lead birds, indexed by relative preference for the shorter IRT, appeared stable for at least five days.

C H A P T E R I I I

RESULTS

As shown in Figure 1, the main results of the Hawkes and Shimp experiment were confirmed. The relative preference of the lead birds for the shorter of two IRT classes varied with the absolute duration of the IRTs. In the .4 sec condition the average relative preference for the shorter of the two IRTs was .625; in the 2 sec condition it was .672, approximately that predicted by the matching law, and in the 8 sec condition it was .875, considerably above the value predicted by the matching law. A linear regression line fit to the data departed significantly from a slope of zero ($p < .05$) for all four birds ($F_{1,12} = 107$ and 97 for Birds B_1 and A_1 respectively, and $F_{1,8} = 281$ and 50 for birds A_2 and B_4 respectively). The individual daily performance of the birds is shown in the Appendix in Table 7. Here, and in all subsequent figures, only data from the last five days of each condition are presented.

Autoshaping in Yoked Birds

Table 3 shows the frequency of keypecking of the yoked birds for every ten presentations of the keylight under each of the IRT conditions. As there was no response-reinforcer contingency

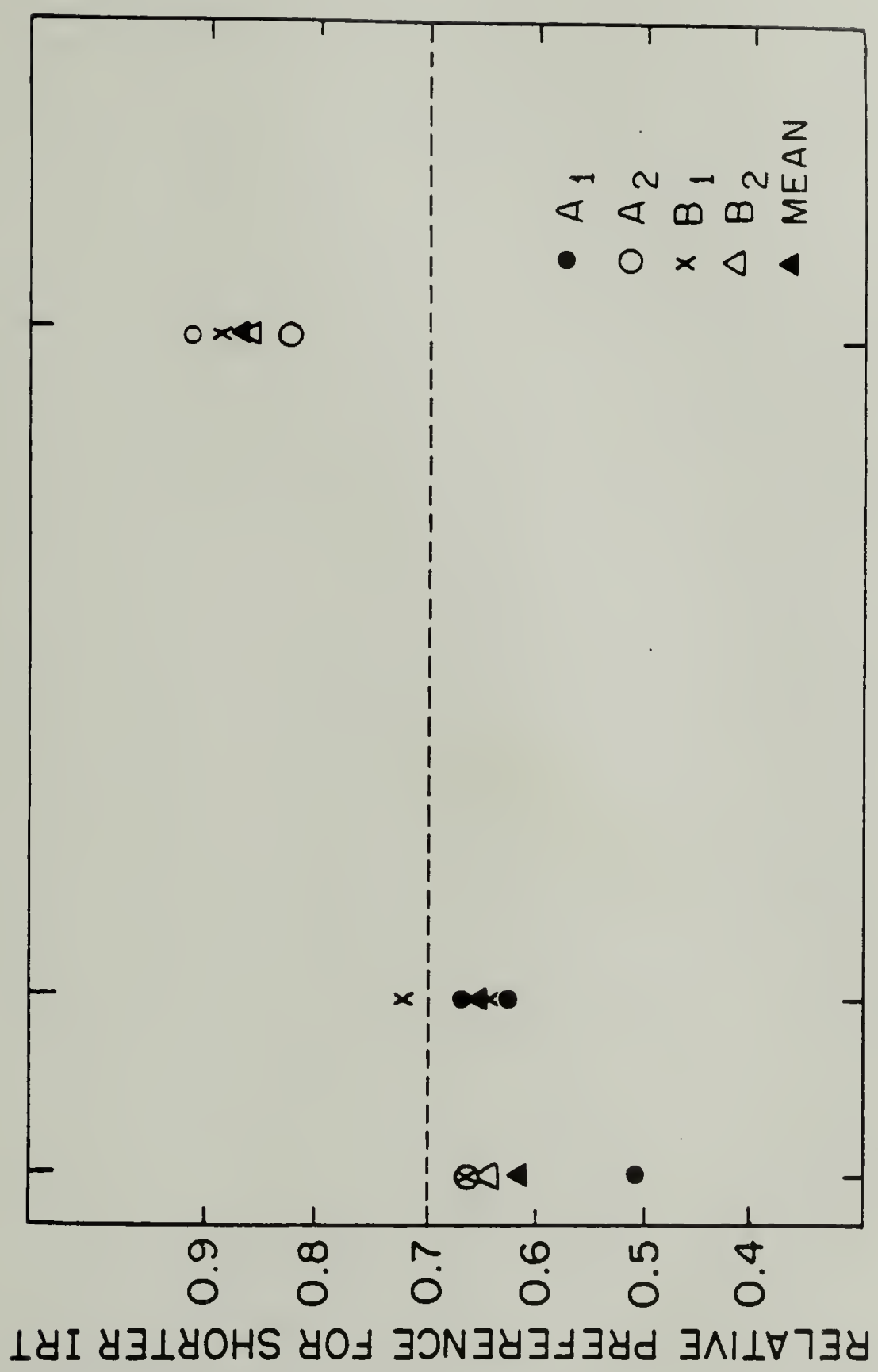

Fig. 1. The relative preference for the shorter of the two reinforced IRT classes for each of the three experimental conditions (indexed by the lower bound of the shorter IRT class). Each point represents the mean of the last five days of each condition. Predidted performance is indicated by the dashed line.

TABLE 3

FREQUENCY OF KEYPECKING IN YOKED BIRDS

Average number of pecks to the key for every ten presentations of the keylight

Bird	IRT condition		
	.4 sec	2 sec	8 sec
A_3			
Pecks to light	.01	.62	1.18
Total pecks	.04	1.04	2.02
A_4			
Pecks to light	0	0	0
Total pecks	0	0	0
B_3			
Pecks to light	.09	.83	3.55
Total pecks	.25	1.86	10.49
B_4			
Pecks to light	.0005	.007	.02
Total pecks	.0006	.01	.09

these keypecks were presumably the results only of autoshaping. For three out of four birds there was considerable keypecking, and the probability of a keypeck to the keylight increased as the absolute duration of the IRTs increased. In addition to pecks to the lighted key, total keypecking has been tabulated, since pecks initiated in the presence of a keylight might have closed the switch after the keylight had gone off. This would have been most likely to occur in the .4 sec condition, with its relatively brief stimulus periods; however, the pattern of responding was essentially the same.

Table 4 shows parametric data that may be relevant to the differences in autoshaping in the three conditions. The 8 sec condition, which fostered the most autoshaping, was distinguished by a lower rate of reinforcement, longer sessions, a greater proportion of time that the keylight was dark, and a higher proportion of reinforced stimulus presentations.

Table 5 shows the amount of keypecking for Birds A_1, A_2, B_1, and B_2 when they were serving as yoked birds. The data are incomplete and somewhat inconsistent. Three of the four birds responded considerably more to the keylight under relatively long IRT conditions. The fourth bird, B_2, responded less in the relatively long IRT condition.

TABLE 4

MEDIAN STIMULUS-REINFORCER PARAMETERS FOR YOKED BIRDS

	IRT condition		
	.4 sec	2 sec	8 sec
% total session keylight on			
A birds	11.1	14.5	3.6
B birds	20.0	18.4	6.1
Reinf./hr			
A birds	36.7	46.2	15.7
B birds	42.8	41.8	25.4
Reinf./stimulus			
A birds	.019	.052	.132
B birds	.014	.049	.123
Total session time (minutes)			
A birds	49	43	115
B birds	42	39	71

TABLE 5

TOTAL KEYPECKING IN BIRDS A_1, A_2, B_1, AND B_2 UNDER YOKED CONDITIONS

Average total number of pecks to the key for every ten stimulus presentations.

Bird	IRT condition		
	.4 sec	2 sec	8 sec
A_1	6.79	---	26.42
A_2	.04	5.88	---
B_1	.39	---	16.21
B_2	---	3.13	.13

Control of Keypecking in Lead Birds

Distribution of responses. Figure 2 shows the relative time allocation of the lead birds as a function of IRT length. Relative time allocation is the percent of total running time that a pigeon spends at a particular IRT. In the ideal case (matching) pigeons would spend 50% of their time in each of the reinforced IRT bins (indicated on the graph by heavy horizontal lines). The abscissa is divided into IRT bins appropriate to the experimental condition. As shown, the lead birds confined responding largely to the two reinforced IRT classes. Considerable pecking occurred just before the onset of the keylight when the reinforced IRTs were two seconds

Fig. 2. Percent of total session time lead birds devoted to different IRT classes (relative time allocation) as a function of IRT length. Horizontal lines indicate IRT classes for which reinforcement was scheduled. Numbers in parentheses indicate the relative time allocated to IRT classes longer than the monitored IRT classes, that is, longer than 1.8 sec, 9.0 sec, and 23.0 seconds for the .4 sec, 2.0 sec, and 8.0 sec conditions respectively. Note that Birds A_1 and B_1 were run twice in the 2.0 sec condition.

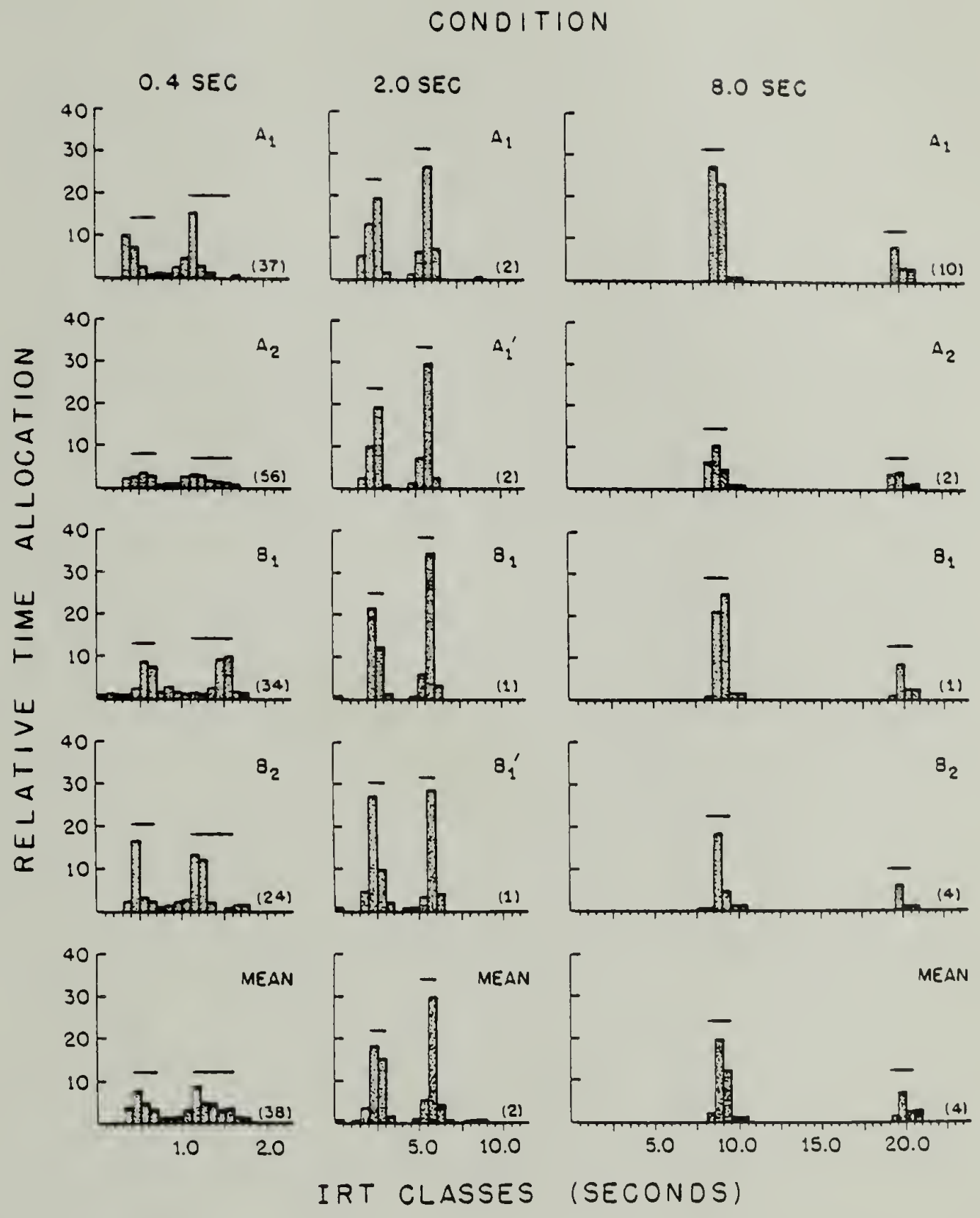
CONDITION
0.4 SEC
2.0 SEC
8.0 SEC
RELATIVE TIME ALLOCATION
40
30
20
10
A1
(37)
A1
(2)
A1
(10)
A2
(56)
A1'
(2)
A2
(2)
B1
(34)
B1
(1)
B1
(1)
B2
(24)
B1'
(1)
B2
(4)
MEAN
(38)
MEAN
(2)
MEAN
(4)
1.0
2.0
5.0
10.0
5.0
10.0
15.0
20.0
IRT CLASSES (SECONDS)

Figure 2

or shorter (the .4 sec condition and the shorter class of the 2 sec condition), but at longer IRTs very little pecking occurred outside the reinforced classes of IRT, and the modal response followed the onset of the keylight by .5 seconds or more. This pattern suggests that there was more exclusive control by the keylight as the duration of the reinforced IRTs increased.

Transfer effects. Transfer effects between conditions indicate to what extent the behavior of the lead birds was independent of the keylight. The only event in the experimental chamber indicating a change of condition was the interval at which the keylight followed keypecks. If keypecking were controlled mainly by the keylight, transfer of optimal performance would be rapid and a relatively high proportion of responses would occur to the lighted key. However, if keypecking were controlled mainly by temporal properties of behavior, keypecks would not coincide with the keylight when conditions changed and a higher percentage of pecks would occur to the dark key. Only when these responses had undergone extinction would we expect responses at other temporal patterns. As shown in Table 6, the extent to which birds confined their pecking to the keylight when changed to a new condition depended, at least in part, on whether the new condition reinforced relatively longer or shorter IRTs than the previous condition. With one anomaly, the results show that relative preference for the lighted key was greater when the previous condition had reinforced

relatively long IRTs. This suggests that control of keypecking by the keylight was an increasing function of IRT duration.

TABLE 6

PERFORMANCE ON THE FIRST DAY OF A NEW CONDITION FOR BIRDS HAVING SERVED AS LEAD BIRDS IN THE PREVIOUS CONDITION

Relative condition change	Previous cond.	Present cond.	Bird	Pecks to dark key	Pecks to lighted key	Relative preference for lighted key
Long to Short	8 sec	2 sec	B_1	227	455	.67
			B_2	288	122	.30
	8 sec	.4 sec	A_1	508	269	.35
			A_2	222	131	.37
	2 sec	.4 sec	B_1	1142	665	.37
			B_1	2019	897	.31
Short to Long	2 sec	8 sec	A_1	2778	199	.07
			A_1	1760	349	.17
	.4 sec	2 sec	A_1	2983	346	.10
			A_2	499	320	.39
	.4 sec	8 sec	B_1	3767	632	.14
			B_2	3728	181	.05

Observational Data

Observations of the birds during sessions revealed that all yoked birds were consistently oriented toward the key or the food hopper. Even A_4, the pigeon that engaged in very little key-pecking, made occasional pecking movements in the direction of the key, indicating that while there was little recorded keypecking there was still stimulus control of key-directed behavior. As all birds, lead and yoked alike, were observed to emit these "airpecks", the recorded pecking is a conservative measure of the control exerted by the key.

It was also observed that the lead pigeons commonly engaged in stereotypic patterns of activity of which the keypeck was only a part. For example, a bird might peck the key, walk to the corner of the chamber, turn to the one-way mirror, and then return to the key in time for the next presentation of the keylight, whereupon the sequence would begin anew. Stereotypic activity of this sort was common in the .4 sec and 2 sec conditions, though in the .4 sec condition the brevity of the reinforced IRTs precluded elaborate interim behavior. (Interim behavior, as used here, merely means any behavior occurring in the interval between successive responses (cf. Staddon and Simmelhag, 1971).) Nonetheless, pigeons in this condition commonly assumed a distinctive posture when passing by an opportunity to respond to the keylight. For example, one pigeon would lower its body, look up at the key and

make an incipient pecking motion when the keylight came on. It would then rise and peck the key on the next presentation of the keylight. In the 8 sec condition there was, of course, always interim behavior between keypecks, but little of it was systematic or stereotypic.

CHAPTER IV

DISCUSSION

The data show that discriminated IRT procedures can, under some circumstances, foster and maintain autoshaping. Three out of four yoked birds acquired the keypecking response, and the fourth bird monitored the key and occasionally directed incomplete pecks at the key, indicating at least some control of keypecking by the keylight. With these procedures then, keypecking has at least two sources of strength, that arising from the response-reinforcer contingency and that arising from the stimulus-reinforcer contingency. Presumably this effect can be found, not just in discriminated IRT procedures, but in any procedure in which a discriminative stimulus is located on the operandum. Under some circumstances this may be an unimportant phenomenon. The contiguity of the stimulus and the reinforcer depends upon the occurrence of a response, and the ability of the stimulus to elicit autoshaping presumably serves merely as a supplementary source of strength. In engineering a bit of behavior we may be indifferent to the origins of the relationship between our procedures and the response in question. The distinction becomes important, however, when we wish to generalize the procedures which vary in the use of discriminative stimuli or when, as in the Hawkes and Shimp study, we wish to compare conditions which

differ in the extent to which they foster autoshaping. Thus we might expect our results to differ if, say, the discriminative stimulus were to appear on the right key while pecking were reinforced on the left, or if the discriminative stimulus were a non-localized tone. In the first case we might expect interference between operant responses to the left key and autoshaped responses to the right key; in the second case we would not expect autoshaping at all. The present results suggest that discriminated IRT procedures should not be used when autoshaped keypecking would be unwelcome.

The Relevance of Autoshaping to Observed Deviations from Matching

While the results of the Hawkes and Shimp experiment appear to be robust, it is not clear what conclusion can be drawn from their data. They found that preference for the shorter of two concurrently reinforced IRTs increased with the interval between stimulus presentations, but autoshaped keypecking in the yoked birds in the present experiment also increased with the interval between stimulus presentations. Little autoshaping was found in the .4 sec condition, somewhat more was found in the 2 sec condition, and considerably more in the 8 sec condition (Table 3). In the 8 sec condition Hawkes and Shimp found overmatching, or a greater-than-predicted preference for the shorter of the two IRT pairs. However, to the extent that a procedure fosters autoshaped keypecking, we should expect overmatching to occur. In order for

the longer of two IRTs to be emitted, the opportunity to terminate the shorter must be passed by. To the extent that a pigeon is autoshaped to peck the keylight when it comes on, the pigeon will show a spurious "preference" for the shorter IRT, for each key-peck terminates the sequence of stimuli. The keylight signalling the longer IRT is not encountered. Since the extent to which a condition fosters autoshaping parallels the extent to which the condition fosters preference for the shorter IRT, it may be that autoshaping accounts, at least in part, for deviations from predicted preference relations among IRTs. It remains an open question whether preference relations among classes of IRTs obey the matching law. As long as a discriminated IRT procedure is used, autoshaping may confound the results.

Relationship of Results to Parametric Studies of Autoshaping

The present results confirm and extend the findings of Gibbon et al. (1977). Perkins et al. (1975), and Terrace et al. (1975). These investigators found that autoshaping was facilitated by long interstimulus intervals, short stimulus durations, and rich schedules of reinforcement. In the present experiment, the lead birds were "on task" most of the time (see Fig. 2) so that, from the perspective of the yoked birds, the interstimulus interval was fairly consistent within a condition. The results confirm the trend of the above findings and extend them to stimulus durations as short as 0.3 seconds, to interstimulus intervals as short as

0.4 seconds and to reinforcement densities as low as one reinforcer per 71 stimulus presentations (see Table 4). Some keypecking was found even at these extreme conditions, though of course it is impossible to say if autoshaped keypecking would have been initially acquired under those conditions. Keypecking, once acquired, may have been maintained in some cases after conditions changed. Thus the analogy to the earlier studies is not exact, but the trend of the data is clearly the same.

On the Validity of Discriminated IRT Procedures

Apart from the question of preference relations among IRTs, interpretation of the present results casts doubt on the validity of the discriminated IRT procedure for any purpose. Discriminated IRT procedures inherently confound sources of control quite apart from any contributions from autoshaping. That a pigeon restricts responding to particular IRTs is meaningless when these IRTs are perfectly correlated with a discriminative stimulus. The very notion of IRTs as a measure assumes that the operant is temporally extended, that what is reinforced is a class of interim behaviors, overt or covert, terminated by a keypeck. A discriminative stimulus, by definition, alters the probability of an operant response. If the keylight alters the probability of a keypeck, the keypeck is not simply the terminal link in a chain of responses, and interresponse times cannot be analyzed as if they were the only source of control. Thus pecking the light is a separate operant

from pecking the key as a temporal discrimination, and results cannot be interpreted in terms of preference among IRT classes (cf. Herrnstein and Loveland, 1975). On the other hand, if the keylight has no effect on keypecking it is a pointless complication, serving only to weaken the force of any results.

It has been argued that the use of a discriminative stimulus sharpens and speeds up acquisition of temporal discriminations without affecting the distribution of responses (Hawkes and Shimp, 1974). However, while the keylight may sharpen the distribution of keypecks, it cannot sharpen the control of pecking by temporal properties of the response. We do not strengthen the control of a response by stimulus A by compounding it with stimulus B. To the contrary, if stimulus B is particularly salient relative to stimulus A we would expect the latter to be overshadowed (Foree and LoLordi, 1973; Miles, 1969); moreover, if stimulus B acquires control of a response before stimulus A, as is implicit in this case, we would expect blocking to occur (Miles, 1970). Thus if the keylight is a better predictor of reinforcement than stimuli arising from a particular sequence of interim responses (as it is almost certain to be under long IRT conditions) we should expect blocking. Not only will the keylight be a supplementary source of strength in its ability to elicit autoshaped keypecks, it may well be by far the most important source of strength by virtue of its role as a discriminative stimulus, blocking control by other discriminative stimuli. These

considerations suggest that visual discriminative stimuli in IRT procedures should be faded out. A discriminative stimulus may be justified in the acquisition of a difficult temporal discrimination provided that it is withdrawn well before the data of primary interest are collected.

Any control of pecking by the keylight as a discriminative stimulus further clouds interpretation of the observed deviations from matching. To the extent that the keylight controls pecking, be it autoshaped or discriminated pecking, overmatching will occur, for pecking the key when the light comes on will prevent the opportunity to peck the keylight signaling a long IRT. Thus any aspect of the procedure that enhances discriminative stimulus control will promote overmatching. As stimulus control is, in general, enhanced by long interstimulus intervals we should expect, in a discriminated IRT procedure, the pattern of overmatching found by Hawkes and Shimp. The greater the duration of the IRTs, and hence the greater the interval between keylight presentations, the greater will be the proportion of keypecks terminating the shorter IRT.

There are two findings from the present experiments that indicate that the keylight did indeed control pecking independently of temporal properties of the response and that this control increased with the absolute duration of the reinforced IRTs.

Evidence from transfer effects. Transfer of optimal performance was virtually immediate when pigeons were shifted from one condition to another in which the IRT durations were relatively short (see Table 6). On the other hand there was considerable perseverence at the previously reinforced rate of responding when they were shifted from the .4 sec condition to either of the other two conditions. For example bird A_1 responded 2983 times to the darkened key over the course of the first session after being transferred from the .4 sec condition to the 2 sec condition, taking over two hours to collect 30 reinforcers at VI 60. Most of these pecks were emitted at the high rate characteristic of responding in the .4 sec condition. Asymptotic performance, indexed by the same bird's behavior after 36 days in this condition, included only 185 pecks to the darkened key, and the reinforcers were collected in about 45 minutes. Bird B_2, on the other hand, transferring from the 8 sec condition (long IRTs) to the 2 sec condition, performed at an optimal level virtually immediately, emitting only 227 pecks to the darkened key and taking 58 minutes to collect 30 reinforcers. In the same condition 36 days later, B_2 emitted 180 pecks to the darkened key and took 51 minutes to collect the 30 reinforcers.

This pattern of results suggests that under the longer IRT conditions the keylight was the controlling stimulus. If temporal properties of the response were controlling stimuli we would expect there to have been a considerable period of extinction

when conditions were changed. There was none. The birds simply responded to the light regardless of its rate of appearance. On the other hand, in the .4 sec condition the temporal properties of the response appear to have been the main controlling stimuli. When conditions were changed, the birds perservered at a high rate of responding regardless of the presence or absence of the keylight.

Evidence from distribution of modal IRTs. Further evidence that the controlling stimulus of keypecking varied from one experimental condition to another is provided by the distribution of responses relative to the onset of the discriminative stimulus. In this experiment there were six reinforced IRT classes in three experimental conditions. In the three IRT classes longer than two seconds, pigeons engaged in almost no keypecking prior to the keylight onset, and the modal IRT followed keylight onset by about .5 sec (see Fig. 2). In the three shorter IRT classes, however, there was considerable pecking that anticipated the onset of the keylight, and the modal response occurred, at least in the two shortest IRT classes, within .1 sec of keylight onset. It is unlikely that a pigeon's behavior is precisely timed at intervals as long as twenty seconds but inaccurate at intervals shorter than two seconds. If temporal properties of behavior were controlling variables at longer IRTs, we would expect keypecks to occur both before and after the appearance of the keylight. Indeed, when Kramer, 1968 (cited in Kramer and Rilling, 1970), reinforced

keypecking on a DRL 20-second schedule without the use of discriminative stimuli, he found considerable responding to IRTs shorter than 20 seconds, with modal responding typically occurring just before the 20 second criterion. This is roughly the pattern found at shorter IRTs in the present study. On the other hand, if the keylight were the main controlling variable at the shorter IRTs, we would not expect so many anticipatory pecks, nor would we expect the modal IRT to occur so soon after keylight onset. These considerations suggest that the keylight was serving as a discriminative stimulus for keypecking for IRTs longer than several seconds, but that temporal properties of the birds' behavior were the main controlling stimuli for the shorter IRTs.

IRTs and Response Classes

It was suggested above that interresponse times as a measure of operant behavior in pigeons may be inappropriate at intervals more than a few seconds in length in discriminated IRT procedures. In the absence of independent evidence that an IRT corresponds to a specific class of interim behavior we ought not to use IRTs as defining characteristics of response classes. Under certain training contingencies, of course, quite long and uniform chains of behavior can be set up, and these chains will be correlated with appropriately long IRTs. However, it does not follow that an arbitrary IRT will always be a useful definition of a response class even if it is scheduled to be reinofrced. Skinner's

(1935) criterion for deciding an appropriate response measure still seems to be apt: use those defining characteristics of both stimulus and response at which the data are most orderly (see also Hawkes and Shimp, 1975). Applied to the present experiment this policy suggests that since keypecking under long IRT conditions was reliably occasioned by the keylight but was not reliably occasioned by the lapse of time or by unspecified interim behavior, the operant was the keypeck and the controlling stimulus was the keylight. Under short IRT conditions, on the other hand, the operant was one or more temporally extended units of behavior terminating in a keypeck, and the controlling stimulus was, among other things, the preceding keypeck.

This interpretation is supported by two further considerations. First, observation of the lead birds under long IRT conditions did not reveal the stereotypic interim behavior characteristic of short IRT conditions. As the behavior was variable, it is unlikely that keypecking was the terminal link of a chain of responses or was reliably occasioned by preceding responses.

Secondly, if keypecks were the terminal links of temporally extended operants in the 8 sec condition, we would expect these operants, as operants, to be more sensitive to contingencies of reinforcement. On the average, the lead birds pecked the keylight signalling the longer IRT only 21 times per session, and 15 of these pecks were reinforced. Despite this high density of reinforcement, the birds spent almost all of their time pecking at the

higher rate (an average of 197 pecks per session for 15 reinforcers). Thus delivery of food did not seem to reinforce keypecks emitted at long IRTs.

It is of course possible to invoke the notion of "preference" for the shorter IRT, but the results can be explained simply in terms of the extinction of a discriminated operant. Under the former interpretation the pigeon is seen as engaging in one of two two alternative operants of different duration; under the latter interpretation the pigeon is seen as engaging in one discriminated operant, undergoing extinction and periodic reconditioning. The sequence of events might run as follows: After collecting a reinforcer for a keypeck terminating the shorter IRT, the pigeon pecks the keylight every time it appears (every eight seconds). If reinforcement is scheduled for the longer IRT, pecking the keylight on every occasion is not reinforced and the behavior undergoes extinction, i.e. there is a progressively reduced probability of pecking the keylight. At some point this changing probability coincides with the condition appropriate for reinforcement, that is, pecking the keylight not on its first presentation but on its second (signalling the longer IRT). Reinforcement of this response raises the probability, not of a 20 second chain of interim behavior, but of the discriminated operant, pecking the keylight. The pigeon again pecks the keylight on virtually every occasion, eventually getting reinforced for doing so if the IV schedule has assigned a reinforcer to the

shorter IRT. Because of the relatively long time between keylight presentations and because of the strength of the discriminated operant, this pattern can be maintained indefinitely.

These considerations suggest that it is best to determine experimentally what the units of behavior are in any given procedure rather than assuming that the "natural line of fracture" of behavior will coicide with the response defined by the reinforcement schedule.

Undermatching at Short IRTs

The present results confirm the findings of Hawkes and Shimp (1974), but suggest that the phenomenon of overmatching at long IRTs may be explained without invoking relative preference among IRT classes. The phenomenon of undermatching at short IRTs, that is, a lower-than-predicted preference for the shorter of two IRT pairs, cannot be explained in the same way. It is possible, however, that the keylight played a role here as well, for the longer of the two reinforced IRT classes in the .4 sec condition was 67% greater in duration than the shorter; that is, the short IRT "window" during which reinforcement was potentially available was 0.3 seconds long (0.4 - 0.7 seconds after the previous response), while the long IRT "window" was 0.5 seconds long (1.1 - 1.6 seconds after the preceding response). It was argued above that under short IRT conditions the keylight was not the primary controlling variable, but it is possible that it served as a

supplementary source of strength. The lower-than-predicted preference for the shorter IRT might simply reflect the fact that the keylight was on for a longer time when it signalled the longer IRT. The probability of a peck controlled by the keylight was greater for the longer IRT than it was for the shorter IRT. Because of this possibility the discriminated IRT procedure is not well-suited for studying preference relations among temporally extended operants, even those of relatively short duration.

Summary

Keypecking in discriminated IRT procedures has two sources of control, that arising from the stimulus-reinforcer contingency and that arising from the response-reinforcer contingency. The contribution of autoshaping, as measured by the frequency of keypecking in yoked birds, increases with the interval between keylight presentations and may be partly responsible for the phenomenon of overmatching found at longer intervals. Thus the discriminated IRT procedure does not permit one to draw strong conclusions about preference relations among IRTs.

An analysis of transfer effects and relative time allocation as a function of IRT length indicates that keypecking at IRTs shorter than several seconds appears to be mainly under the control of temporal properties of responding, but at longer IRTs the keylight appears to be the main controlling stimulus, possibly blocking control by temporal properties of responding. Therefore,

in a discriminated IRT procedure the time between keypecks may not be a valid criterion of a response class in the absence of evidence that the class, so defined, varies in an orderly way with environmental events.

NOTES

[1]To be consistent with Hawkes and Shimp (1974) the matching prediction is based on the relative reciprocal of the shorter IRT, but the prediction is essentially the same if we simply use the midpoints of the IRT classes in the formula:

$$\frac{\frac{L}{S}}{\frac{L}{S} + 1}$$

where L = midpoint of longer IRT and S = midpoint of shorter IRT. The predicted preference for the shorter IRT using this formula is:

.4 sec condition	.71
2 sec condition	.71
8 sec condition	.70

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APPENDIX

TABLE 7

DISTRIBUTION OF KEYPECKS: INDIVIDUAL DATA

The absolute frequency of keypecking for the last five days of each condition is shown for all birds. Columns indicate, respectively, the number of keypecks to the stimulus signalling the shorter IRT (S_1), to the stimulus signalling the longer IRT (S_2), the total number of keypecks, and the percent of those keypecks to the keylight that terminated the shorter IRT class (% S_1). The last day of each condition is presented in the top row for each bird, the second-to-last day in the second row, and so on.

TABLE 7 CONTINUED

.4 sec Condition: B Birds

	Condition 2 (B_1 lead)				Condition 5 (B_2 lead)			
Bird	Pecks to S_1	Pecks to S_2	Total pecks	$\%S_1$	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$
	591	296	1803	67	7	7	55	50
	493	268	1575	65	29	8	85	78
B_1	597	310	1970	66	14	8	68	64
	710	394	1990	64	11	11	69	50
	904	373	2055	71	27	6	90	82
					894	349	1815	72
					941	480	2038	66
B_2	(Did not run)				792	468	1692	63
					688	437	1533	61
					844	486	1815	63

TABLE 7 CONTINUED

.4 sec Condition: B Birds

Bird	Condition 2 (B_1 lead)				Condition 5 (B_2 lead)			
	Pecks to S_1	Pecks to S_2	Total pecks	$\%S_1$	Pecks to S_1	Pecks to S_2	Total pecks	$\%S_1$
	5	6	40	45	2	2	23	50
	15	19	71	44	6	5	49	55
B_3	11	10	56	52	3	6	37	33
	11	13	62	46	7	11	49	39
	9	8	47	53	18	13	103	58
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	1	0
B_4	0	1	3	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0

TABLE 7 CONTINUED

.4 sec Condition: A Birds

Bird	Condition 3 (A_2 lead)				Condition 6 (A_1 lead)			
	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$
	337	227	1330	60	195	338	1258	37
	297	233	1139	56	204	245	1371	45
A_1	219	158	832	58	531	306	2006	63
	241	194	1103	55	442	357	1617	55
	209	133	841	61	498	373	1878	57
	389	193	1800	67	0	2	10	0
	351	180	1229	66	0	1	3	0
A_2	319	159	1202	67	0	1	2	0
	293	170	1133	63	0	0	2	0
	351	136	1114	72	1	6	16	14

TABLE 7 CONTINUED

.4 sec Condition: A Birds

Bird	Condition 3 (A_2 lead)				Condition 6 (A_1 lead)			
	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$
	0	0	0	0	1	1	3	50
	0	0	1	0	0	1	4	0
A_3	0	0	3	0	1	1	13	50
	1	1	4	50	3	3	12	50
	0	0	1	0	4	2	19	67
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
A_4	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	1	0
	0	0	0	0	0	0	0	0

TABLE 7 CONTINUED

2 sec Condition: B Birds

Bird	Condition 1 (B_1 lead)				Condition 4 (B_1 lead)			
	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$
	322	149	776	68	299	140	677	68
	328	155	757	69	258	114	595	69
B_1	249	180	644	58	339	112	715	75
	258	122	542	69	328	89	696	79
	271	145	588	65	304	119	643	72
					22	3	195	88
					11	2	123	85
B_2	(Did not run)				21	2	207	91
					35	7	244	83
					27	1	182	96

TABLE 7 CONTINUED

2 sec Condition: B Birds

Bird	Condition 1 (B_1 lead)				Condition 4 (B_1 lead)			
	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$
	401	137	956	74	26	31	129	46
	257	111	691	70	36	33	131	52
B_3	244	147	701	62	19	23	101	45
	207	114	553	64	20	16	95	56
	227	125	635	64	24	22	111	52
	3	0	8	100	0	0	0	0
	0	0	2	0	1	0	1	100
B_4	4	1	6	80	1	0	1	100
	0	2	2	0	0	0	0	0
	3	1	11	75	0	0	0	0

TABLE 7 CONTINUED

2 sec Condition: A Birds

	Condition 1 (A_1 lead)				Condition 4 (A_1 lead)			
Bird	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$
	287	142	607	67	226	144	472	61
	278	135	600	67	193	134	427	59
A_1	277	146	555	65	231	142	496	62
	236	126	537	65	230	122	456	65
	279	120	599	70	293	124	575	70
					223	110	404	67
					197	87	347	69
A_2	(Did not run)				179	84	313	68
					175	64	306	73
					177	54	283	77

TABLE 7 CONTINUED

2 sec Condition: A Birds

Bird	Condition 1 (A_1 lead)				Condition 4 (A_1 lead)			
	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$
	4	1	7	80	29	10	58	74
	3	8	15	27	38	10	77	79
A_3	13	9	34	59	38	6	67	86
	19	21	58	48	15	0	36	100
	4	4	19	50	19	7	53	73
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
A_4	0	0	1	0	0	0	1	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0

TABLE 7 CONTINUED

8 sec Condition: B Birds

	Condition 3 (B_2 lead)				Condition 6 (B_1 lead)			
Bird	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$
	151	24	305	86	156	24	334	87
	112	29	246	80	201	20	436	91
B_1	367	45	578	89	138	23	339	86
	82	15	161	85	175	23	402	88
	173	26	294	87	190	24	437	89
	102	17	256	86	0	0	0	0
	113	19	324	86	0	0	3	0
B_2	142	21	291	87	0	0	6	0
	104	19	234	85	0	0	3	0
	141	18	271	89	0	0	0	0

TABLE 7 CONTINUED

8 sec Condition: B Birds

	Condition 3 (B_2 lead)				Condition 6 (B_1 lead)			
Bird	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$
	72	17	285	81	17	1	100	94
	84	20	302	81	16	0	156	100
B_3	144	16	354	90	13	1	138	93
	108	27	310	80	18	0	96	100
	112	21	299	84	25	7	141	78
	0	0	0	0	3	0	4	100
	0	0	0	0	0	0	2	0
B_4	0	0	0	0	0	0	0	0
	0	0	3	0	1	0	1	100
	0	0	1	0	2	0	2	100

TABLE 7 CONTINUED

8 sec Condition: A Birds

Bird	Condition 2 (A_1 lead)				Condition 5 (A_2 lead)			
	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$
	199	23	328	90	66	14	533	82
	210	19	340	92	101	15	587	87
A_1	232	17	384	93	74	16	462	82
	203	20	334	91	66	12	433	85
	253	19	419	93	60	13	664	82
					96	27	196	78
					131	25	222	86
A_2	(Did not run)				127	25	222	84
					116	21	220	85
					117	24	210	83

TABLE 7 CONTINUED

8 sec Condition: A Birds

	Condition 2 (A_1 lead)				Condition 5 (A_2 lead)			
Bird	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$	Pecks to S_1	Pecks to S_2	Total Pecks	$\%S_1$
	8	2	30	80	21	10	75	68
	9	2	17	82	45	15	97	75
A_3	18	3	39	86	18	4	36	82
	0	0	1	0	60	13	94	82
	0	0	1	0	9	3	20	75
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
A_4	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0